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Prevalence of antigens and antibodies against SARS-CoV-2 in people deprived of liberty

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Abstract *Aiming to estimate the prevalence of anti-SARS-CoV-2 antigens and antibodies among incarcerated individuals, an institution-based serological survey was conducted in seven prison units across four municipalities in the state of Piauí, Brazil, from April to October 2022. A probabilistic cluster sampling method was adopted. Interviews, rapid tests, and serological assays were performed to detect anti-SARS-CoV-2 antigens and antibodies. Prevalence rates, statistical associations using the chi-square test, and prevalence ratios through Poisson regression were calculated. Among the 848 participants, antigen prevalence was 1.1%. The prevalence of anti-SARS-CoV-2 antibodies ranged from 6.5% (IgM-S) to 98.9% (IgG-S). No significant differences were observed in antigen prevalence. The prevalence of IgG-N and IgG-S antibodies was higher among inmates in Teresina (PR=1.41; 95%CI: 1.08-1.46; PR=1.03; 95%CI: 1.01-1.05). Receiving at least two doses of a COVID-19 vaccine increased antibody seropositivity (IgM-S PR=2.08; 95%CI: 1.01-4.29; IgG-N PR=1.26; 95%CI: 1.08-1.46; IgG-S PR=1.02; 95%CI: 1.01-1.04). These findings reinforce the positive impact of vaccination and other control measures implemented in the incarcerated population during the COVID-19 pandemic.*

Key words *COVID-19, SARS-CoV-2, Prisoners, Epidemiological Surveys, Prevalence*

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Introduction

The pandemic caused by the rapid spread of the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) virus has forced drastic changes in daily life for the general population, including restrictions on social contact, the need for isolation, and the adoption of new daily practices, such as the use of face masks, alcohol-based hand sanitizers, and frequent hand hygiene[1].

The challenges of controlling the virus have become even more acute for incarcerated individuals, given the specific conditions and vulnerabilities observed in prison units (PUs), which have become a major focus of concern during the COVID-19 pandemic. It is estimated that the transmission rate of the SARS-CoV-2 virus in these settings may be significantly higher than in the general population. While an infected person outside of prison transmits the virus to one or two people, a single inmate can potentially infect up to 10 people, including other inmates, correctional officers, service providers, and visitors, posing a considerable risk not only for the spread of the disease within prisons, but also for the entire community outside the prison[2,3].

To illustrate how the prison environment is conducive to the spread of SARS-CoV-2, in Brazil, in June 2020, 4,256 cases of COVID-19 were recorded among prisoners and staff, with 58 deaths. In a span of only 30 days, this represented a 24.1% increase compared to previous months[4].

In this context, measures were implemented to contain the spread and circulation of SARS-CoV-2 in prisons. Most countries have suspended group activities, visits, and transfers, in addition to reducing the number of inmates, limiting new admissions, adopting alternative measures for serving sentences, and conducting timely mass testing[5].

In the USA, mass testing in prisons showed that the prevalence of SARS-CoV-2 reached positivity levels of 86.8%. This strategy enabled the identification of new cases, helping to prevent the spread of the virus and providing a more accurate assessment of the prevalence of COVID-19. As a result, the number of confirmed cases increased from 642 to 8,239, representing a 1.5 to 157-fold increase in each facility[6].

Early case detection and seroprevalence monitoring are essential to implementing effective control measures, protecting both the prison population and the community. Given this context, this study aims to estimate the prevalence of anti-SARS-CoV-2 antigens and antibodies in incarcerated individuals in the state of Piauí.

The research results seek to improve healthcare in Piauí, inform prevention strategies, improve health policies, reduce virus transmission, strengthen prison health infrastructure, and prepare authorities for future pandemics, promoting equity and strengthening incarcerated individuals' right to health.

Material and methods

This is an analytical cross-sectional, institutional-based serological survey, based on the WHO protocol[7] to investigate the seroprevalence of SARS-CoV-2 and map exposure to the virus among prisoners.

The state of Piauí has 14 PUs, housing approximately 4,297 prisoners. Seven prisons were included in the study, selected by the Piauí State Department of Justice (*Secretaria de Justiça do Piauí* – SEJUS-PI), as they represent approximately 80% of the state's prison population. These PUs are strategically located in four municipalities in different regions: one prison in Parnaíba, in the north; four prisons in the metropolitan area, including the cities of Teresina (three prisons) and Altos (one prison), located in the central region; and two prisons in the city of Picos, in the south. Among the selected institutions, three have Prison Primary Care Teams (PPCTs), established according to the criteria of the National Policy for Comprehensive Health Care for Prisoners in the Prison System (*Política Nacional de Atenção Integral à Saúde das PPL no Sistema Prisinal* – PNAISP).

The study population consisted of inmates of both sexes, present in the seven prisons on the days of data collection, carried out between April and October 2022.

The sample size was calculated on the OpenEpi® platform, version 3.01, using the equation: n = [*EDFF * Np(1-p)] / [(d2 / Z2 1-α/2 * (N-1) + p * (1-p)*], where N = the size of the inmate population in the selected prisons (N=3,498); p = expected prevalence of 50%; EDFF = cluster design effect of 2.0; d = tolerable error of 5%; and Z = standard normal distribution score of 1.96 (defined by the 95% confidence level). The minimum number of inmates was 693, plus 20%

to compensate for possible refusals and absences due to the constant transfers that occur in the dynamics of prison systems. Thus, the final sample size was 832 incarcerated individuals.

A single-stage probability cluster sampling method was adopted, with the cell being considered the primary sampling unit (PSU). In prisons with more than 30 inmates, cells were randomly selected using probability proportional to size (PPT) sampling.

To determine the number of cells to be randomly selected, the average number of inmates per cell was calculated, considering the ratio between the total number of inmates and the number of cells. Dividing the sample size of each prison with more than 30 inmates (n=808) by the average number of inmates per cell determined the number of cells in which the interviews should be conducted (n=113). In the two prisons with fewer than 30 inmates, no random selection of cells was performed; all inmates present on the day of the interview were included in the survey at two women's institutions located in Parnaíba and Picos.

The interviews were conducted using an electronic form with standardized and structured questions, with variables adapted from instruments used in other COVID-19 surveys conducted in Brazil[1,2,8-10].

The device used for data collection was a tablet running the EpiCollect app, a platform developed for data collection, storage, and dissemination[11]. While inside the prisons, the tablets operated offline. At the end of the collection day, the devices were connected to the internet outside the units in order to transfer the data from the interviews conducted that day.

The dependent variables were positive results from tests for detecting anti-SARS-CoV-2 antigen and antibodies: a) rapid antigen test (no, yes); b) serology for anti-nucleocapsid immunoglobulin G – IgG-N (no, yes); c) serology for anti-spike immunoglobulin G – IgG-S (no, yes); d) serology for anti-spike immunoglobulin M – IgM-S (no, yes).

The independent variables were: a) Prison location (Altos, Parnaíba, Picos, Teresina); b) Sex (female, male); c) Age range (18-24, 25-34, 35-73 years); d) Skin color (white, Black [black+brown], others [yellow+Indigenous]); e) Education (up to elementary school, high school or higher); f) Soap and water in the cell (no, yes); g) Reported comorbidities (none, one or more); h) Symptoms related to COVID-19 (none, one or more); i) Self-reported prior diagnosis of COVID-19 (no, yes); j) COVID-19 vaccine (≥2 doses) (no, yes).

Before data collection began, each prison unit was asked for an updated list of incarcerated individuals, organized by pavilion and cell. This list was used to randomly assign cells and identify participants who would be included in the study sample, generating a code for each participant and estimating the amount of material used daily.

Nasopharyngeal secretion samples were collected via nasal swab for rapid antigen testing for SARS-CoV-2, using the Rapid COVID Ag Test kit from the Paraná Institute of Molecular Biology (IBMP), designed for the qualitative detection of SARS-CoV-2 viral antigens in patients suspected of having COVID-19 or who had had contact with infected individuals (https://www.ibmp.org.br/).

Venous blood samples of 5 mL were also collected by one of the nursing professionals on the collection team in accordance with biosafety regulations. At the end of the collection shift, blood samples were placed in thermal boxes and transferred to the laboratory, where they remained at room temperature for a maximum of four hours before being centrifuged at 500g for ten minutes to remove the serum. The serum samples were aliquoted and frozen at -20°C in the Laboratory of Parasitology and Sanitary Entomology (LAPES/UFPI). The samples were then transferred to the Serology Laboratory of the Fiocruz-Ceará Diagnostics Unit (UNADIG/FIOCRUZ-CE), where all serology tests were performed.

Serum samples were used to detect the presence of IgM antibodies to the spike protein (S) and IgG antibodies to the S protein and nucleocapsid (N) of SARS-CoV-2, using serology by means of the chemiluminescence immunoassay (CLIA) method. The presence of antibodies was verified using the Abbott Architect i2000SR (Abbott®) (https://www.abbott.com).

To compensate for differences in sample draw probabilities, design weights were introduced during the data analysis stage, expressed as the inverse of the sampling fractions (F=1/f). The design weight can be understood as the number of prison inmates represented for each inmate interviewed.

The data were analyzed in Stata, version 16.1, using the survey module and adhering to the complex sampling plan and sample weighting. Prevalence rates, prevalence ratios (PR), and respective 95% confidence intervals (95%CI) were calculated for different outcomes according to

independent variables using Poisson regression with robust variance. Pearson's chi-square test was used to assess the association between the independent variables and the outcomes of interest, at a 5% significance level.

The project was authorized by SEJUS-PI and approved by the Research Ethics Committee of the Federal University of Piauí, according to opinion no. 4,578,002, dated March 8, 2021. The ethical guidelines for research involving human subjects, as per resolution 466/2012, were followed. All participants were informed of the study objectives, risks, and benefits. The individuals who agreed to participate in the study signed the Informed Consent Form.

Results

A total of 848 incarcerated individuals were evaluated. The majority of respondents were male (95.5%), aged 25 to 34 (40.0%), black (84.6%), had completed elementary school (70.9%), and had access to soap and water in their cells (98.0%). Approximately one-third of the sample reported some type of comorbidity or chronic condition (33.7%). Symptoms related to COVID-19 were reported by 71.5% of the inmates. One in five inmates reported a previous diagnosis of COVID-19 (22.2%), and 67.0% reported having received two or more doses of the COVID-19 vaccine. All inmates underwent rapid antigen testing, with only 1.1% of them being diagnosed with current infection, with no statistical difference according to the variables explored in this analysis (Table 1).

The prevalence of anti-SARS-CoV-2 IgG-N antibodies in incarcerated individuals was 55.4%. A statistically significant association was found in relation to the following variables: Teresina PU (64.7%; PR=1.41; 95%CI: 1.19-1.65; p<0.001) and having received two or more doses of the COVID-19 vaccine (59.3%; PR=1.26; 95%CI=1.08-1.49; p<0.05) (Table 2).

The prevalence of IgG-S anti-SARS-CoV-2 antibodies in incarcerated individuals was 98.9%, which proved to be significantly higher among inmates of PUs located in Teresina (100%; PR=1.03; 95%CI: 1.01-1.05; p=0.005), with a previous diagnosis of COVID-19 (100%; PR=1.01; 95%CI: 1.01-1.02; p=0.002) and among those who reported having received two or more doses of the COVID-19 vaccine (99.6%; PR=1.02; 95%CI: 1.01-1.04; p=0.027). The prevalence of anti-SARS-CoV-2 IgG-S antibodies was significantly lower among male inmates (98.8%; PR=0.99; 95%CI: 0.98-0.99; p<0.002) and among those who had soap and water available in their cells (98.9%; PR=0.99; 95%CI: 0.98-0.99; p=0.002) (Table 3).

The prevalence of anti-SARS-CoV-2 IgM-S antibodies was 6.5%, which proved to be significantly lower among inmates who had soap and water in their cells (6.1%; PR=0.23; 95%CI: 0.08-0.71; p=0.011) and twice as high among those who reported having received two or more doses of the COVID-19 vaccine (7.8%; PR=2.08; 95%CI: 1.01-4.29; p=0.049) (Table 4).

Chart 1 shows the vaccines administered to the study population. The Janssen, AstraZeneca, and Pfizer vaccines target the spike (S) protein directly, while CoronaVac targets the nucleocapsid (N) protein.

Discussion

This serological survey investigated the prevalence of anti-SARS-CoV-2 antigens and antibodies in incarcerated individuals in Piauí. Rapid antigen tests (Ag-RDTs) yielded 1.1% SARS-CoV-2 antigen positivity, while serological tests yielded 55.4% IgG-N, 98.9% IgG-S, and 6.5% IgM-S positivity, demonstrating a low prevalence of active SARS-CoV-2 infection and considerable immunity induced by immunobiologicals or previous infections. The results provided insight into the behavior of the virus within the prison environment.

The present study used one of the strategies recommended for combating COVID-19 within prison units: mass testing among prisoners. Two types of tests were performed: rapid antigen detection tests (Ag-RDTs) and serological tests that analyzed the S and N proteins, chosen for analysis due to their serodiagnostic capacity and ability to statistically predict immune responses to the COVID-19 vaccine.

The results revealed a high prevalence of IgG-S antibodies, suggesting immunity acquired through vaccination or previous infections. By contrast, the low antigen detection rate (1.1%) indicates a low active circulation of the virus among participants. Rapid antigen tests have demonstrated limitations in asymptomatic populations and have proven to be more effective in symptomatic individuals. Furthermore, they provide results in minutes, helping to provide an early interruption of the chain of transmission in patients with SARS-CoV-2[12].

Table 1. Prevalence of the SARS-CoV-2 antigen in incarcerated individuals according to sociodemographic and clinical variables. Piauí, 2022.

Variables	Total		SARS-CoV-2 antigen reagent				p-value[a]
	n	%*	n	%*	RP	95%CI	
Total	848	100.0	10	1.1	-	-	-
Prison location							
Altos	224	26.2	3	1.3	1.00	-	-
Parnaíba	146	14.7	4	2.6	1.93	(0.46-8.12)	0.367
Picos	126	14.3	-	-	-	-	-
Teresina	352	44.8	3	0.8	0.57	(0.12-2.77)	0.482
Sex							
Female	86	4.5	2	2.5	1.00	-	-
Male	762	95.5	8	1.0	0.40	(0.08-1.91)	0.250
Age range (in years)							
18-24	275	32.6	5	1.4	1.00	-	-
25-34	330	40.0	1	0.3	0.23	(0.03-1.96)	0.176
35-73	242	27.4	4	1.7	1.22	(0.33-4.46)	0.762
Skin color							
White	118	13.9	1	0.8	1.00	-	-
Black (black+brown)	717	84.6	8	1.0	1.22	(0.15-10.06)	0.853
Others (yellow+Indigenous)	13	1.5	1	5.5	6.53	(0.42-100.76)	0.177
Educational level							
Up to complete elementary	601	70.9	6	1.0	1.00	-	-
≥High School	247	29.1	4	1.4	1.40	(0.37-5.39)	0.617
Soap and water in the cell							
No	16	2.0	1	6.5	1.00	-	-
Yes	832	98.0	9	0.9	0.15	(0.02-1.17)	0.070
Reported comorbidities							
None	552	66.3	7	1.2	1.00	-	-
One or more	296	33.7	3	0.8	0.64	(0.15-2.79)	0.549
Symptoms related to COVID-19							
None	239	28.5	4	1.7	1.00	-	-
One or more	609	71.5	6	0.8	0.47	(0.12-1.77)	0.263
Prior diagnosis of COVID-19							
No	657	77.8	8	1.2	1.00	-	-
Yes	191	22.2	2	0.7	0.55	(0.09-3.26)	0.509
Vaccine against COVID-19 (≥2 doses)							
No	279	33.0	3	0.9	1.00	-	-
Yes	569	67.0	7	1.2	1.35	(0.30-6.03)	0.690

Notes: The total refers to the number of inmates who agreed to have biological samples collected and may vary depending on the type of test performed. *Weighted percentage. PR: prevalence ratio; 95%CI: 95% confidence interval. aPearson's chi-square test.

Source: Authors.

Studies conducted by the University of Wisconsin using rapid antigen tests for COVID-19 in asymptomatic individuals showed sensitivity levels of only 40% in the study group, demonstrating ineffectiveness in accurately detecting the virus, resulting in a high rate of false negatives. Furthermore, 67% of positive results in asymptomatic individuals were false, compromising diagnostic reliability and underestimating the true prevalence of the disease[13].

The Ag-RDT test is performed by applying practical kits using a swab that identifies viral particles in the collected sample. The result is available on average in 15 to 60 minutes and is not as accurate as it may seem, given that it lacks 100% sensitivity and specificity. Therefore,

Table 2. Prevalence of IgG-N anti-SARS-CoV-2 antibodies in incarcerated individuals according to sociodemographic and clinical variables. Piauí, 2022.

Variables	Total		IgG-N reagent				p-value[a]
	n	%*	n	%*	RP	95%CI	
Total	811	100.0	442	55.4	-	-	-
Prison location							
Altos	215	26.2	99	46.1	1.00	-	-
Parnaíba	132	14.0	66	48.1	1.04	(0.83-1.31)	0.711
Picos	123	14.6	57	50.2	1.09	(0.89-1.33)	0.403
Teresina	341	45.2	220	64.7	1.41	(1.19-1.65)	<0.001
Sex							
Female	80	4.5	39	51.9	1.00	-	-
Male	731	95.5	403	55.5	1.07	(0.78-1.46)	0.669
Age range (in years)							
18-24	263	32.4	140	53.7	1.00	-	-
25-34	317	40.2	186	59.2	1.10	(0.94-1.30)	0.224
35-73	230	27.4	116	52.0	0.97	(0.81-1.15)	0.714
Skin color							
White	112	13.8	56	50.8	1.00	-	-
Black (black+brown)	686	84.6	380	56.4	1.11	(0.92-1.24)	0.273
Others (yellow+Indigenous)	13	1.6	6	42.2	0.83	(0.51-1.37)	0.463
Educational level							
Up to complete elementary	574	70.9	316	55.9	1.00	-	-
≥High School	237	29.1	126	54.0	0.97	(0.83-1.12)	0.650
Soap and water in the cell							
No	16	2.1	9	56.2	1.00	-	-
Yes	795	97.9	433	55.4	0.98	(0.59-1.65)	0.955
Reported comorbidities							
None	531	66.5	290	54.8	1.00	-	-
One or more	280	33.5	152	56.4	1.03	(0.90-1.17)	0.679
Symptoms related to COVID-19							
None	232	28.8	122	53.6	1.00	-	-
One or more	579	71.2	320	56.1	1.05	(0.88-1.25)	0.617
Prior diagnosis of COVID-19							
No	628	77.9	343	55.4	1.00	-	-
Yes	183	22.1	99	55.2	0.99	(0.85-1.17)	0.971
Vaccine against COVID-19 (≥ 2 doses)							
No	262	32.5	123	47.2	1.00	-	-
Yes	549	67.5	319	59.3	1.26	(1.08-1.46)	0.003

Notes: The total refers to the number of inmates who agreed to have biological samples collected and may vary depending on the type of test performed. *Weighted percentage. PR: prevalence ratio; 95% CI: 95% confidence interval. aPearson's chi-square test.

Source: Authors.

a single negative test should not be used as a criterion for excluding a COVID-19 diagnosis and should always be combined with other, more specific tests when symptoms are suspected[14,15].

Ag-RDTs are most effective when used in the acute phase of the disease, as this is when patients experience increased viral replication and symptoms. Although not indicated for use in asymptomatic individuals, they can be administered to contacts of positive cases, especially in populations living in crowded areas, such as among incarcerated individuals. The ideal time to administer them is between 5 and 7 days after the onset of the initial symptoms[15].

Ag-RDTs use the lateral flow immunodetection method, capable of identifying SARS-

Table 3. Prevalence of IgG-S anti-SARS-CoV-2 antibodies in incarcerated individuals according to sociodemographic and clinical variables. Piauí, 2022.

Variables	Total		IgG-S reagent				p-value[a]
	n	%*	n	%*	RP	95%CI	
Total	811	100.0	802	98.9	-	-	-
Prison location							
Altos	215	26.2	209	97.2	1.00	-	-
Parnaíba	132	14.0	131	99.1	1.02	(0.99-1.05)	0.145
Picos	123	14.6	121	98.1	1.01	(0.98-1.04)	0.560
Teresina	341	45.2	341	100	1.03	(1.01-1.05)	0.005
Sex							
Female	80	4.5	80	100.0	1.00	-	-
Male	731	95.5	722	98.8	0.99	(0.98-.099)	0.002
Age range (in years)							
18-24	263	32.4	262	99.6	1.00	-	-
25-34	317	40.2	313	98.8	0.99	(0.98-1.06)	0.245
35-73	230	27.4	226	98.1	0.98	(0.96-1.01)	0.140
Skin color							
White	112	13.8	111	99.1	1.00	-	-
Black (black+brown)	686	84.6	678	98.8	0.99	(0.98-1.02)	0.752
Others (yellow+indigenous)	13	1.6	13	100.0	1.01	(0.99-1.03)	0.323
Educational level							
Up to complete elementary	574	70.9	569	99.1	1.00	-	-
High School or higher	237	29.1	233	98.3	0.99	(0.97-1.010)	0.385
Soap and water in cell							
No	16	2.1	16	100.0	1.00	-	-
Yes	795	97.9	786	98.9	0.99	(0.98-0.99)	0.002
Reported comorbidities							
None	531	66.5	524	98.7	1.00	-	-
One or more	280	33.5	278	99.3	1.01	(0.99-1.02)	0.400
Symptoms related to COVID-19							
None	232	28.8	229	98.7	1.00	-	-
One or more	579	71.2	573	98.9	1.01	(0.98-1.02)	0.751
Prior diagnosis of COVID-19							
No	628	77.9	619	98.6	1.00	-	-
Yes	183	22.1	183	100.0	1.01	(1.01-1.02)	0.002
Vaccine against COVID-19 (≥ 2 doses)							
No	262	32.5	255	97.4	1.00	-	-
Yes	549	67.5	547	99.6	1.02	(1.01-1.04)	0.027

Notes: The total refers to the number of inmates who agreed to have biological samples collected and may vary depending on the type of test performed. *Weighted percentage. PR: prevalence ratio; 95%CI: 95% confidence interval. aPearson's chi-square test.

Source: Authors.

CoV-2 proteins, primarily the viral nucleocapsid, in respiratory tract secretions. Their sensitivity is 94% and their specificity reaches 97%[16].

In Utrecht, in the Netherlands, and in Aruba, community COVID-19 testing centers evaluated the performance of rapid antigen tests on 1,369 individuals. Of these, 101 tested positive on the rapid antigen test, with a high viral load. False-negative results were observed in individuals with low viral loads, reinforcing the efficacy and reliability of these tests when performed on individuals with high viral loads and symptoms[17].

In this study conducted with incarcerated individuals in Piauí, antibody detection by sero-

Table 4. Prevalence of anti-SARS-CoV-2 IgM-S antibodies in incarcerated individuals according to sociodemographic and clinical variables. Piauí, 2022.

Variables	Total		IgM-S reagent				p-value[a]
	n	%*	n	%*	RP	95%CI	
Total	810	100.0	51	6.5	-	-	-
Prison location							
Altos	214	26.2	10	4.7	1.00	-	-
Parnaíba	132	14.0	3	1.9	0.42	(0.10-1.77)	0.234
Picos	123	14.6	7	5.9	1.26	(0.52-3.01)	0.604
Teresina	341	45.2	31	9.2	1.97	(0.92-4.21)	0.080
Sex							
Female	80	4.5	4	5.3	1.00	-	-
Male	730	95.5	47	6.6	1.25	(0.35-4.52)	0.731
Age range (in years)							
18-24	263	32.4	10	3.8	1.00	-	-
25-34	317	40.2	24	7.7	2.03	(0.91-4.50)	0.081
35-73	229	27.4	17	8.1	2.14	(0.91-5.01)	0.079
Skin color							
White	112	13.8	7	6.0	1.00	-	-
Black (black+brown)	685	84.6	44	6.7	1.11	(0.45-2.73)	0.816
Others (yellow+Indigenous)	13	1.6	-	-	-	-	-
Educational level							
Up to complete elementary	574	70.9	36	6.3	1.00	-	-
High School or higher	236	29.1	15	7.0	1.11	(0.61-2.01)	0.729
Soap and water in cell							
No	16	2.1	4	26.0	1.00	-	-
Yes	794	97.9	47	6.1	0.23	(0.08-0.71)	0.011
Reported comorbidities							
None	530	66.5	35	7.0	1.00	-	-
One or more	280	33.5	16	5.6	0.80	(0.42-1.49)	0.474
Symptoms related to COVID-19							
None	231	28.8	15	6.8	1.00	-	-
One or more	579	71.2	36	6.4	0.95	(0.52-1.71)	0.855
Prior diagnosis of COVID -19							
No	627	77.9	38	6.2	1.00	-	-
Yes	183	22.1	13	7.5	1.20	(0.64-2.26)	0.567
Vaccine against COVID -19 (≥2 doses)							
No	261	32.5	10	3.8	1.00	-	-
Yes	549	67.5	41	7.8	2.08	(1.01-4.29)	0.049

Notes: The total refers to the number of inmates who agreed to have biological samples collected and may vary depending on the type of test performed. *Weighted percentage. PR: prevalence ratio; 95%CI: 95% confidence interval. aPearson's chi-square test.

Source: Authors.

logical tests revealed values of 55.4% for IgG-N, 98.9% for IgG-S, and 6.5% for IgM-S. Because the S and N proteins were used in the production of certain vaccines administered to the study population, the positivity is presumed to represent a vaccine-induced immune response. On the other hand, positive antibodies against the N protein suggest an immune response to a previous SARS-CoV-2 infection, i.e., prior COVID-19.

Antibody analysis is an effective strategy to understand and combat a disease, as it allows for the identification of individuals infected with SARS-CoV-2. Although results take longer to become available, this method detects the presence of IgM, which is produced in the early

Chart 1. Vaccines available in Prison Units in the state of Piauí, 2021-2023.

Prison Units	1st dose	2nd dose	3rd dose	Booster	Target protein
Femina - Teresina	CoronaVac (Jun/21)	CoronaVac (Jul/21)	CoronaVac (Feb/22)		N and S
Professor José Ribamar Leite -Teresina	Janssen (Jun/21)	Janssen (Jun and Jul/21) AstraZeneca (Feb/22)			S
Irmão Guido - Teresina	AstraZeneca (May/21)	Astrazeneca (Aug/21-Sept/22) Pfizer (Apr/23)	Janssen (Jul/21) Pfizer (Sept/22)	Janssen (Feb/22)	S
		CoronaVac (Sept/22)			N and S
Pref. Adalberto de Moura Santos - Picos	AstraZeneca (Jun/21)	AstraZeneca (Sept/21)	Janssen (Mar/22)	AstraZeneca (Aug/22) Pfizer (Jun/23)	S
José de Deus Barros - Picos	Pfizer (Jun/21)	Pfizer (Sept/21)	Pfizer (Feb/21)	Pfizer (Aug/22)	S
Juiz Fontes Ibiapina - Parnaíba	Coronavac (Jun/21-22)	Coronavac (Feb-Jun/22)			N and S
			AstraZeneca (Feb/22)		S

Notes: N: Nucleocapsid and S: Spike.

Source: SEJUS-PI, 2023.

stages of infection and is a widely used marker to identify early or acute infections. IgG, in turn, indicates past infection, with or without symptoms, and allows for the identification of medium- and long-term immune responses, whether natural or vaccine-induced[18,19].

IgG and IgM immunoglobulins are detected in serological tests at different times: IgM usually appears about 10 days after the onset of symptoms, while IgG is usually identified after 15 days. IgG remains in the body for a longer period of time when compared to IgM, reflecting the body's immune response to the infectious agent[20].

The immune response to COVID-19 results in the production of antibodies that prevent reinfection by SARS-CoV-2 within a short period of time after the disease. The virus has two structural proteins (S and N) that directly affect the immune response. Specific antibodies bind to the S protein, the receptor-binding domain (RBD), or S1, blocking the virus's interaction with the host cell's angiotensin-converting enzyme (ACE2) receptor, preventing its entry into the cell. Furthermore, antibodies against the N protein interfere with viral replication, hindering the formation of new viral particles within the cell[21].

Tests to detect IgG-S and N antibodies are used to determine whether a person has been exposed to the virus or developed an immune response after vaccination. These antibodies typically appear weeks after infection or immunization and can remain in the body for months or even years[22,23].

The N protein contains antigenic foci responsible for stimulating the production and multiplication of antibodies as part of the natural immune response after infection. By contrast, the S glycoprotein is responsible for binding to the cell membrane, facilitating the entry of the virus into the host cell and initiating the infectious process[24].

Due to this fundamental role in the virus's contact with the host cell, these proteins have become targets in the production of several vaccines, particularly the S protein. The Pfizer-BioNTech vaccines primarily target the S protein, using messenger RNA to encode the S protein. AstraZeneca and Janssen are based on non-replicating viral vectors that also utilize the S protein. CoronaVac, an inactivated virus vaccine,

offers a broader immune response, involving both the S and N proteins[25].

Most of the vaccines administered in the study's emergency units induced the production of neutralizing antibodies that target the S protein, preventing infection by blocking the virus's entry into cells. This explains the higher proportion of IgG-S antibodies when compared to IgG-N antibodies.

Serological tests for COVID-19 analyze these viral proteins and detect the presence of antibodies in blood, plasma, or serum, which can indicate past or current infections, as well as the effectiveness of the immune response to vaccination. The sensitivity of the tests may vary depending on the progression of the disease, which tends to be lower in the initial phases, as their effectiveness depends on the quantity of antibodies produced, which varies depending on the manifestation of symptoms[26].

The S protein may indicate both a response to vaccination and an immune response that persists in individuals for prolonged periods after a COVID-19 infection. Some reports have revealed a high prevalence of memory B cells specific to the RBD domain of the S protein, with 92.9% of the cases showing immunity within 2 to 3 months and 80.6% within 4 to 5 months[27].

This finding was confirmed in another study that revealed that IgG-S circulates in the body for a longer period of time than does IgG-N. This may be explained by a vaccine response. Given the use of the S protein in vaccine production, another possibility raised would be reinfection, as well as its ability to persist longer within the body after infection[28].

Another study also justified the use of the S protein in COVID-19 vaccine production due to its unique performance in viral binding, allowing the virus to enter the host cell through its RBD domain. As a result, neutralizing antibodies are produced, which act by blocking interaction with the receptor, inducing an immune response against COVID-19[29].

Monitoring the N protein serves as a tool to monitor the virus in asymptomatic patients. This was revealed in a study conducted with healthy blood donors in Milan, analyzing the seroprevalence of SARS-CoV-2, resulting in a significant detection of IgG-N antibodies in this population who did not present symptoms of COVID-19 at the time of collection[30].

However, a longitudinal serological analysis of SARS-CoV-2 infection after convalescence demonstrated that, regardless of disease severity, individuals developed a long-lasting immune response to COVID-19 and maintained stable levels of IgG-N and S antibodies for up to 8 months[31,32].

Furthermore, it is important to note that there are risk factors that can increase vulnerability to COVID-19. Variables such as age, sex, skin color, education, and comorbidities, explored in this study, can influence both susceptibility to infection and disease severity[33].

Regarding this, one study conducted in São Paulo with severe hospitalized patients and deaths related to COVID-19 revealed that the majority of hospitalized patients were male and had a higher risk of worsening and mortality from COVID-19 due to a greater number of comorbidities and adherence to risk behaviors, such as alcohol and tobacco consumption, occupational exposure, and immunological differences[34]. Another study, also conducted in São Paulo, which analyzed COVID-19 cases that resulted in death, found that the majority of positive cases involved black and brown males, with a low level of education, a low income, and who lived in crowded housing conditions and in vulnerable areas[35,36].

By contrast, it is important to emphasize that the population in this study had access to ideal hygiene and protective equipment. However, a lack of adequate guidance on how to use them properly may have resulted in inappropriate use of these resources. This can, paradoxically, increase the risk of contamination and further spread the virus, rather than reduce its spread[37,38].

In short, being incarcerated compromises an individual's health, increasing susceptibility to infections and intensifying the severity of diseases, such as COVID-19, especially in precarious health and environmental conditions. Prisons pose a constant risk of coronavirus infection, in part due to transmission by asymptomatic carriers and the presence of infectious diseases and other chronic conditions in this population, in addition to environmental factors that favor increased viral circulation.

The analysis of immune responses through IgG-N, S, and IgM-S antibodies, whether natural or induced by immunobiological agents, enabled a greater understanding of the behavior of the virus in the prison environment, given the containment strategies adopted. This investigation also contributed to evaluating the effectiveness of vaccines administered to this population, providing insights into the situation of incarcerated individuals and the effective-

ness of measures implemented to combat the COVID-19 pandemic. Hence, this study offers a detailed overview of the living conditions of individuals in PUs.

However, this study does present some limitations: the turnover of prisoners in some prison cells, which required new drawings and cell checks before beginning data collection; the unavailability of a private space to answer the questionnaire, which may have generated influence or embarrassment due to the presence of other inmates in the same cell and correctional officers; and the short daily timeframe for data collection, which needed to be adjusted to the prison routine to ensure security and avoid interfering with regular activities.

To mitigate the impact of turnover, we suggest analyses that consider data from fixed and dynamic groups separately. Furthermore, inter-institutional agreements should be in place to ensure the continuity of data collection with participants transferred between units. Regarding the lack of privacy, individual interviews in private spaces within the confines of the prison environment or the use of self-administered questionnaires on electronic devices are recommended to increase the confidentiality of responses. Despite these limitations, all stages and objectives of the study were achieved.

Conclusion

This research provided insight into the prevalence of SARS-CoV-2 antigens and antibodies among incarcerated individuals in Piauí. The study demonstrated a low prevalence of active SARS-CoV-2 infections (1.1%) and a high prevalence of IgG-S antibodies (98.9%) among incarcerated individuals, attributed to immunization and prior exposure. These findings reinforce the effectiveness of the implemented vaccination and control measures. Furthermore, only 6.5% of the participants had IgM-S antibodies, which may reflect recent infections.

These data, combined with the variables explored in this study, suggest that vaccination measures were effective in containing the active spread of the virus and promoting a protective immune response in the prison population.

The evidence presented in this study provides a solid basis for evaluating public policies implemented during the pandemic in PUs. Finally, this study contributes to the historical record of the spread of COVID-19, providing important data that can be used in actions carried out by the Justice and Health agencies responsible for assisting incarcerated individuals, as well as in future research conducted with this population.

Collaborations

LO Fernandes was responsible for the construction of the article, from the selection of the subject, the conjuncture, the analysis and the discussion of the results, as well as the review. MTP Rodrigues and A Sousa were responsible for the methodology and submission of the ethics committee. JC Penha, JCG Lira Neto, MHG Fonseca and AP Madeiro were responsible for the analysis and review of the manuscript. MDM Mascarenhas was responsible for the construction of the entire manuscript, such as methodology, analysis of the data, assembly of the results and discussion of the results.

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Data availability statement

The data sources adopted in the research are indicated in the article's body.

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